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During a few years past the attention of scientific men and of agriculturists has been called to some varieties of Phosphatic Guano found on several small islands of the tropical Pacific and imported to this country and to Europe under the name of "American Guano."

The principal ingredient of these guanos is the phosphate of lime, with which is combined in the various sorts more or less phosphate of magnesia, sulphate of lime, organic matter and water. They generally contain traces of ammonia with a small percentage of soluble salts, but these, which, without doubt, formed an important part of the guano as it originally existed, have now almost entirely disappeared in consequence of the various changes to which the deposits have been subjected.

* Much of the chemical investigation of which the results are given in this paper I made in the Sheffield Laboratory of Yale College, the facilities of which were kindly afforded me by my friends, Profs. Brush and Johnson, to whom I am happy to express my thanks for this favor, and for their valuable assistance in the prosecution of my work. Also to my brother, Mr. Arnold Hague, one of their students, my acknowledgments are due for analytical aid. J. D. H.

The first samples of these guanos were taken from Jarvis' and Baker's Islands in 1855 and sent to the United States for examination, the results of which led in 1858 to the occupation and working of the deposits. The importance and value of these having once become evident, the Pacific, within a few degrees north and south of the equator, was carefully explored and many other islands were visited, on a few of which beds of guano of some extent were discovered.

In the following paper I propose to describe some of these. I shall have reference chiefly to Baker's, Howland's and Jarvis' Islands, on each of which I resided several months for the purpose of studying the character and formation of their deposits. I also spent some months in exploring this region of the Pacific and visiting many other islands, having a small vessel employed especially for that object. In this service, altogether, I was engaged more than two years, from 1859 to 1861 inclusive, in the employ of William H. Webb, Esq., of New York, by whose courtesy I am permitted to publish these results.

These islands are all of coral formation. They are situated near the equator and between the meridians of about 155° and 180° longitude west from Greenwich. They are without fresh water and almost entirely destitute of vegetation, and are the resort of countless thousands of birds whose accumulated ordure and dead bodies have formed extensive deposits.

Baker's Island.—This island possesses the most important of these deposits. It is situated in lat. 0° 13′ north and long. 176° 22′ west from Greenwich. Excepting Howland's Island, forty miles distant, it is very remote from any other land. It presents the usual features of an ordinary coral island. It is surrounded by a fringing reef, which is from 200 to 400 feet wide and slightly elevated above the sea level at low tide. It is about one mile long and two-thirds of a mile wide, trending east and west. The surface is nearly level, the highest point of which is twenty-two feet above the level of the sea, showing some evidences of elevation.*

* The accompanying engraving exhibits a section of the western (lee) beach which was cut through for a railway. LL is the level of the reef of which the seaward end P is the shore platform or plateau covered at high tides by five and a half feet

of water. From the shore to the edge of the guano deposit G, is from 300 to 400 feet. The perpendicular height from LL to the summit of the sand beach, SS, is twenty-two feet, and the depth of the excavation opposite this highest point is ten feet, the drawing being a little out of proportion.

The dotted line, *ab*, represents an old beach formation which the cut exposed. It consists of large and small coral fragments and shells beneath which the sand lies in compact strata. This formation was evidently once the surface of the island, and

Above the crown of the beach there is a sandy ridge which encircles the guano deposit. This marginal ridge is about one hundred feet wide on the lee side of the island, and is there composed of fine sand and small fragments of corals and shells mixed with considerable guano; on the eastern or windward side it is much wider and formed of coarser fragments of corals and shells which, in their arrangement, present the appearance of successive beach formations. This margin is partially covered with a rank growth of long, coarse grass, portulacca, mesembryanthemum, and a few other species of plants.

Encircled by this ridge lies the guano deposit occupying the centre and the greater part of the island. The surface of this deposit is nearly even, but the hard coral bottom which forms its bed has a gradual slope from the borders towards the centre, or, perhaps more properly, from northwest to southeast, giving the guano a variable depth from six inches at the edges to several feet at the deepest part. None of the grass that grows abundantly on the margin is found on the guano, but there are one or two species of portulacca occurring in certain parts, (particularly where the guano is shallowest and driest), and to this is owing the presence of the fine roots and fibres in some of the guano.

The entire deposit presents considerable uniformity in character. Excepting some isolated spots of little extent there is no outer crust, and the guano of the surface differs but little, if any, from that below. There is, however, some variety in the appearance of the guanos of the deep and shallow parts of the deposit. On the northern side it is from six to twelve inches deep; is generally quite dry, and is a dark brown pulverulent substance of rather coarse grain or texture, containing many thread-like roots and fibres and whitish particles, among which Prof. Liebig observed scattered crystals of the phosphate of magnesia and ammonia.* It is closely though not hard packed, and is readily

may be traced from *a* to *b*, where the guano rests upon it. Above it lies a sandy ridge, SS, a comparatively new beach accumulation rather indistinctly stratified. The highest point of *ab* is fifteen feet above LL, which altitude, in accordance with the commonly accepted theory that the sea-made coral land does does not exceed ten feet in height, would, of itself, be an evidence of elevation and, consequently, to account for the present height of twenty-two feet, it would be necessary to suppose a subsequent subsidence in order to allow SS to accumulate, and finally another elevation of the whole to its present position. It must be observed, however, that the sandy ridge, SS, only prevails at this altitude on the southwestern shore, and probably violent westerly gales and heavy seas have had much to do with its formation. My own observations favor the opinion that the sea-made coral land may reach a greater altitude than ten or twelve feet. During the prevalence of high surf at Jarvis Island I have known seas to wash up the beach with body and force sufficient to carry away plank and spars that were lying on the crown of the beach eighteen feet above the level of the reef.

* Liebig's Report on Baker and Jarvis Guanos, Aug. 7th, 1860.

removed by shovels without the aid of picks. In this part of the deposit the portulacca flourishes most.

The guano on the southern side is of reddish color, of finer texture, much damper, and of less specific gravity than that just described. There is much less vegetation in this part of the deposit, and the guano here contains scarce any roots or fibres.

Chemically these varieties do not differ very much. Usually the darker sort contains less water and more organic (vegetable) matter, from which it probably derives its color.

Analyses of these two sorts are given beyond.

Much light may be thrown on the formation of these deposits by the analysis, (I) which follows, showing the composition of recently deposited guano. The sample itself does not represent any considerable part of the existing deposit, but was taken from a locality where large numbers of birds are still accustomed to congregate. It is the dung of the Pelicanus Aquilus, commonly called the Frigate Bird, which of all the birds frequenting the island is the only one whose recent evacuations are of such a consistency that they may conveniently be collected. They contain a large proportion of solid matter, while the evacuations of nearly all the other birds are very thin and watery. It is found in their favorite roosting places, and shows the character of guano before it has long been subjected to the influence of the weather. It is a light and dry substance, consisting of friable grains or fine powder, of a brown color, smelling strongly of ammonia. Of the three following analyses No. I is this freshly deposited guano; No. II is of the light colored guano from the deeper part of the deposit, and No. III of the dark guano from the shallow part.

	I.	II.	III.
Moisture expelled at 212° Fahr.,	10·40	2·92	1·82
Loss by ignition,	36·88	8·32	8·50
Insol. in HCl, (unconsumed by ignition),	·78	...	...
Lime,	22·41	42·74	42·34
Magnesia,	1·46	2 54	2 75
Sulphuric acid,	2·36	1·30	1·24
Phosphoric acid,	21·27	39·70	40 14
Carbonic acid, chlorine and alkalies, undet.,	4·44	2·48	3·21
	100·00	100·00	100·00
Sol. in water remaining after ignition,	3 63		

No. I contained 3·82 per cent of actual ammonia and all contain traces of iron. I also obtained in sample I. a strong reaction for uric acid.

This sample (No. I) resembles Peruvian guano in many respects, and leads to the conclusion that the difference between that and the American guano is mainly owing to circumstances of climate.

In some parts of the deeper deposit a light scale or crust has formed over the surface, which is generally very thin though occasionally hard pieces are found varying from half an inch to

an inch in thickness. The thin scale is met with particularly where there is, or has been, any moisture, and, after showers, where pools of water have been standing for some time, such a crust appears on drying. There seems to have been a similar process in the formation of the thicker crust, for it is found only occasionally in places of which the dampness and general appearance indicate that water may have assisted at its formation.

The thinner pieces are found not only on the surface, but in certain localities form strata at various depths, usually about an inch apart, with intermediate layers of guano. These strata seem to have been formed at intervals during the accumulation of the guano deposit each one at some time having itself formed the surface and now marking a period in its age.

Each of the localities where these strata occur, although on opposite sides of the deposit are at the edges and immediately adjoining the marginal ridge already described and from their proximity to the shore it seems possible that these may have been subjected to occasional floods by high seas washing over the crown of the beach.

The following is an analysis of a thick and hard piece of crust found on the surface:—

Loss by ignition (water and little organic matter)	11·7500
Lime	40·93
Magnesia	·74
Phosphoric acid	40·47
Sulphuric acid	5·66
Loss and undetermined	·45
	100·00

The small amount of magnesia and the excess of sulphuric acid are points worthy of notice.

This crust is formed on Baker's Island only to a limited extent, but its existence there and character are interesting when compared with the Jarvis Island deposits, the better part of which is all crust and in which, as Johnson and Leibig have observed, much of the phosphoric acid is combined as the neutral phosphate of lime. The same is true of this crust of Baker's Island.

Before referring to the climate, birds etc. of this island, I will first give some description of Howland's and Jarvis' Islands.

Howland's Island.—About forty miles in a north northwest direction from Baker's, is situated Howland's Island in lat. 0° 51′ north and 176° 32′ west from Greenwich. It is about a mile and a half long by a half mile wide, containing, above the crown of the beach, an area of some 400 acres. The highest point is seventeen feet above the reef and ten or twelve feet above the level of the high tide. It trends N.N.W. and S.S.E. The general features of the island resemble those of Baker's. Its surface, at least on the western side, is somewhat depressed and much of it is covered by a growth of purslane, grass and other vegetation

like that on Baker's Island, but considerably more abundant. Near the centre of the island there are one or two thickets of leafless trees or brushwood, standing eight or ten feet high and occupying an area of several acres. The tops of these trees, in which the birds roost, are apparently quite dead but the lower parts near the roots, show signs of life after every rain. The windward side of the island is formed by a succession of ridges composed of coral debris with some sand and shells, running parallel to the eastern beach, each one of which may, at earlier stages of the island's growth, have successively formed the weather shore. Occasionally among these ridges a sandy bed is met with in which some little guano is mixed. On the lee side there is also a sandy margin of considerable width. Bits of pumice and pieces of driftwood are scattered all over the island's surface.

The main deposit of guano occupies the middle part of the island and stretches, with some interruptions of intervening sand, nearly from the north to the south end. Its surface is even and in many places covered by a thick growth of purslane whose thread-like roots abound in the guano where it grows. The deposit rests on a hard coral bottom and varies in depth from six inches to four feet. The fact, already observed at Baker's, that vegetation flourishes most where the guano is shallow is also quite apparent here and the consequent characteristic difference between the guano of the deep and shallow parts is distinctly marked. The first variety, from the deeper part, is a fine pulverulent substance of reddish brown color, usually a little damp in its native bed and almost quite free from roots or fibers. The latter is of rather coarser texture, quite black and containing many delicate roots and fibers and much vegetable matter. The following analyses exhibit their comparative quality. No. 1 is of the deep part, No. 2 of the shallow part of the deposit.

	No. 1.	No. 2.
Moisture at 212° Fahr.	1·83	4·12
Loss by ignition	8·65	22·63
Insol. in HCl (unconsumed organic) matter	1·95	2·00
Lime	42·	36·90
Magnesia	2·65	1·24
Sulphuric acid	1·33	·58
Phosphoric acid	39·65	30·80
Carb. acid, chlorine and alkalies undeterm'd,	1·94	1·67
	100·00	100·00

It will be seen that the main difference in these samples is in the volatile matters present. Discarding the water and the organic matter, comparative analyses of the *ash* would vary but little.

Some interesting pseudomorphs occur buried in the guano of this island. Coral fragments of various species were found that had long been covered up under the deposit and in some of which the carbonic acid had been almost entirely replaced by phosphoric acid. In such I have found seventy per cent phosphate

of lime. In many others the change was only partial and, on breaking some of these, in the centre was usually found a nucleus or *core* of coral still retaining its original hardness and composition, while the external parts had been changed from carbonate to phosphate which, though soft and friable, still preserved the structure and appearance of the coral.

Jarvis' Island.—Jarvis' Island is situated in lat. 0° 22′ south and long. 159° 58′ west from Greenwich. It is nearly two miles long by one mile wide, trending east and west, and containing about 1000 acres. Like Baker's and Howland's it has the general features of a coral island, but it differs from them essentially in the fact that it once contained a lagoon which has gradually been filled up with sand and detritus, while the whole island has undergone some elevation. It therefore presents a basin-like form, the surface being depressed from the outer edge towards the centre. It is encircled by a fringing reef, or shore platform, about 300 feet wide; from this a gradually sloping beach recedes, the crown of which is from eighteen to twenty-eight feet high, forming a ridge or border, of varying width, which surrounds the island like a wall, from the inshore edge of which the surface of the island is gently depressed.

Within this depression there are other ridges, parallel to the outer one, and old beach lines and water marks, the remaining traces of the waters of the lagoon, marking its gradual decrease and final disappearance.

This flat depressed surface in the centre of the island is about seven or eight feet above the level of the sea. It bears but little vegetation, consisting of long, coarse grass, mesembryanthemum, and portulacca, and that is near the outer edges of the island where the surface is formed of coral sand mixed with more or less guano. In the central and lower parts the surface is composed of the sulphate of lime, and it is on this foundation that the principal deposit of guano rests. This feature of Jarvis' Island is an important one to consider in studying the difference between the guano found on it and that on Baker's Island, for it readily explains the presence, in much of the Jarvis Guano, of the great excess of sulphate of lime, remarked by all who have investigated it, while the unequal mechanical mixture of the guano with the underlying sulphate accounts for the lack of uniformity in different samples.

In examining the foundation of the guano deposit on Baker's or Howland's Islands, by sinking a shaft vertically, the hard conglomerate reef rock is found directly underlying the guano. Resting on this foundation the guano has undergone only such changes as the climate has produced. On Jarvis' Island, however, after sinking through the guano, one first meets with a stratum of sulphate of lime (sometimes compact and crystalline, sometimes soft and amorphous) frequently two feet thick, beneath

which are successive strata of coral sand and shells deposited one above the other in the gradual process by which the lagoon was filled up.*

Of the origin of this sulphate of lime there can hardly be any doubt. As the lagoon was nearly filled up, while, by the gradual elevation of the island, the communication between the outer ocean and the inner lake was constantly becoming less easy, large quantities of sea water must have been evaporated in the basin. By this means deposits would be formed containing common salt, gypsum and other salts found in the waters of the ocean. From these the more soluble parts would gradually be washed out again by the occasional rains, leaving the less soluble sulphate of lime as we find it here.

Some additional light is thrown on this matter by the different parts of the surface, which, though nearly flat, shows some slight variety of level. The higher parts, particularly around the outer edges, are composed chiefly of coral sand, either mixed with or underlying guano. Nearer the centre is a large tract, rather more depressed, forming a shallow basin in which the bulk of the sea water must have been evaporated, and whose surface (now partly covered with guano) is a bed of sulphate of lime, while, further, there is a still lower point, the least elevated of the whole, where the lagoon waters were, without doubt, most recently concentrated. This latter locality is a crescent shaped bed, about 600 feet long by 200 or 300 feet wide, having a surface very slightly depressed from the outer edge towards the middle. Around the borders are incrustations of crystallized gypsum and common salt, ripple marks and similar evidences of the gradually disappearing lake. The whole is composed of a crystalline deposit of sulphate of lime, which, around the borders, as already observed, is mixed with some common salt, while near the centre, where rain water sometimes collects after a heavy shower, the salt is almost entirely washed out, leaving the gypsum by itself. It is closely, but not hard, packed, and is still very wet. By digging 18 or 24 inches down, salt water may generally be found.

These facts help us to understand the varying conditions in which we now find the guano beds, since the most important part, and that from which the importations have thus far come, rests on a bed of sulphate of lime, of an earlier but similar origin to that just described above: a part rests on a coral formation, while still another part, covering a large tract, has been by the action of water mixed with coral mud.

The first named deposit, lying on the sulphate of lime bed, has a peculiar character. It is covered by, or consists of, a hard

* These horizontal strata were penetrated to a depth of about twenty feet. They were composed chiefly of fine and coarse sand with an occasional stratum of coral fragments and shells.

crust that is from one-fourth of an inch to an inch and a half in thickness, beneath which lies a stratum of guano varying in depth from one inch to a foot. In many places where the guano was originally shallow the whole is taken up and formed into the hard crust which then lies immediately on the sulphate. This crust, when pure, is snow-white, with an appearance somewhat resembling porcelain, but is usually colored more or less by organic matter. Generally it is very hard, and strongly cohesive, though sometimes friable, and it lies unevenly on the surface in rough fragments that are warped and curved by the heat of the sun. It consists chiefly of phosphoric acid and lime, but, owing to the variable amount of sulphate of lime with which it is mechanically mixed, there is a lack of uniformity in different samples. Hence the percentage of phosphoric acid varies from over 50 per cent to less than 30 per cent.

The phosphoric acid and lime, moreover, are not combined in constant proportions, some existing as bone phosphate, the greater part, doubtless, in most specimens, as the neutral phosphate, and, possibly, a part as the superphosphate.

The following is an analysis of a piece of pure crust. The sample, in question, was a snow-white fragment, containing scarcely any organic matter.

Moisture at 212° Fahr.,	·12
Loss by ignition, (combined water with little organic matter),	9·62
Lime,	38·32
Sulphuric acid,	1·63
Phosphoric acid,	50 04
Undetermined and loss,	·27
	100·00

This presents a somewhat remarkable character. It appears to be a nearly pure di-phosphate of lime. After allowing to the sulphuric acid the requisite amount of lime, there remains enough of the latter to form ninety per cent of the salt $2CaO, HO, PO_5$ leaving an excess of about three per cent of phosphoric acid, which would suggest the possibility that a part of the phosphoric acid and lime may be combined as $CaO, 2HO, PO_5$.

So small an amount of sulphuric acid is also noticeable in a specimen of Jarvis guano which usually contains a large percentage of that acid, but in this case it is owing to the purity of the crust and the absence of mechanically mixed sulphate of lime.

Samples of Jarvis guano have been examined by many chemists, but their results are not always uniform, because, as I have already explained, their samples were *mixtures* of this crust and the underlying guano or gypsum. A number of analyses, made for commercial purposes by Prof. Johnson of New Haven, I find published in a guano pamphlet, issued by Mr. Webb as a trade circular. Prof. Liebig has also published a very complete analy-

sis of Jarvis guano in his "Report on the Guanos of Baker's and Jarvis' Islands, Aug. 7th, 1860."

The following presents some of the results obtained by these two chemists:

	Liebig.	Johnson. Average of four samples.
Lime,	34·839	34·79
Phosphoric acid,	17·601	18·48
Sulphuric acid,	27·021	20·75

In Johnson's samples nearly the whole of the phosphoric acid is combined with the lime as $2CaO, HO, PO_5$, while Liebig finds for the above,

$3CaO, PO_5$,	17·397 per cent.
$2CaO, HO, PO_5$,	16·026 "

The formation of the neutral phosphate in this guano I think may be considered as a result of the action of sea water to which this part of the deposit has been subjected. It will be remembered that in describing the Baker's Island deposit I gave an analysis of a piece of crust found there, in which the phosphoric acid was likewise partly combined as the neutral salt. In that crust was also noticed a much larger percentage of sulphuric acid than is found in the guano from which it was formed; and, further, it was observed that on Baker's Island this crust only occurs in places of which the appearance and position indicate that water (probably from high seas washing over the crown of the beach) assisted at its formation. It seems to me probable, under these circumstances, that sulphates resulting from the evaporation of the sea water have been decomposed, and that the sulphuric acid has united with the lime of the bone phosphate, causing the formation of the di-phosphate of lime.

That this process may have been carried on to a much greater extent at Jarvis' Island, where much of the deposit has evidently long been acted upon by sea water, seems to me beyond a doubt.

A singular feature is presented by this crust in the formation of so-called 'hummocks,' an idea of which may be better obtained from the accompanying cuts than from words. These 'hummocks'

vary in diameter from one to ten inches and in height from half an inch to six or seven inches. The exterior is composed of the hard, phosphatic crust, while within each one, without exception, there is a central mass of soft, amorphous and nearly pure hydrated sulphate of lime. When one of these is cut through ver-

tically the section shows a series of concentric layers above and around this central mass. The exterior is almost pure phosphate, and, proceeding from the outside towards the centre, each successive layer has less phosphate and more sulphate until the central mass is reached, which is almost pure sulphate. It is worthy of note that this hydrated sulphate of lime, which invariably fills the centre of a "hummock," is amorphous and exceedingly fine and soft, even when the underlying gypsum is crystalline. These hummocks are scattered over certain parts of the deposits and occur in close proximity to each other. In these places the deposit is invariably damp, and, usually, beneath each one may be found, mixed with the underlying sulphate, a black, earthy and damp substance containing much phosphate and some carbonate of lime. This black substance was, probably, coral mud, in which, as in the coral pseudomorphs of Howland's, the carbonic acid has been expelled and replaced by phosphoric acid, and this affords the only explanation that I can offer for this remarkable formation, namely, that in the chemical interchange that must have taken place between the soluble salts washed down from the guano on the surface, the sulphate of lime and the coral mud, there may have been an excess of carbonic acid liberated from the latter and replaced by phosphoric acid. The surface guano was probably wet and in a plastic state like thick mud, and the ascending carbonic acid, finding no other means of escape, and exerting an upward force, produced these hummocks, which have since become dry and hard.

In those parts of the crusted deposit where there are no "hummocks" the surface is usually a little higher and the deposit below drier than where the hummocks occur, and this would furnish a reason for their absence, since the hummocks could hardly be formed, as above explained, if the surface, for want of moisture, were not sufficiently plastic and yielding.

Thus this guano has not only been deprived of its ammoniacal salts, uric acid, etc., as have the deposits of Baker's and Howland's, but by its immediate contact with the gypsum has undergone further chemical and physical changes. Probably, too, the direct action of sea water has effected much by bringing together and mixing the guano with the bed on which it lay, and, by occasional inundations, exposing the whole alternately to the action of water and to the intense heat of the sun.* Thus it has been baked into a thick and hard crust whose chemical composition differs materially from the guano in its usual form.

* McKean's and Phœnix Islands, described below, are likewise old lagoons not yet elevated so high as Jarvis's. Their basins are sometimes flooded at high tides by several inches of water. Thus we may suppose that Jarvis, in an earlier stage of the process of elevation, was subjected to occasional floods, keeping in mind the fact before mentioned, that by digging now in the lower parts of the island salt water may be found at no great distance below the surface.

I have said that there was beneath the crust a stratum of guano of variable depth. Frequently it is wanting altogether, the whole being taken up in the crust and lying in immediate contact with the bed of gypsum. Where there is such a layer of guano it is variable in composition, being mixed with more or less sulphate of lime.

It generally contains from sixty to seventy per cent phosphate of lime.

I come now to speak of that part of the Jarvis deposit which rests on a *coral* foundation. This is of limited extent, but is of great interest because of its similarity to the Baker guano. It is about two feet deep; is a dry powder of dark brown color, of rather lighter shade than the Baker guano, owing to the presence of less vegetable matter. It contains very little coral sand mixed with it. The following is an analysis:

Moisture at 212° Fahr.,	5·02
Loss by ignition,	8·45
Lime,	42·17
Magnesia,	1·02
Sulphuric acid,	3·06
Phosphoric acid,	34·01
Carbonic acid,	·81
Insol. residue, (organic matter unconsumed by ignition),	·60
Chlorine, alkalies, iron, etc.,	4·86
	100 00

It is important to observe that while the greater part of the Jarvis guano, as already described, differs materially from the Baker, *this portion* of the Jarvis deposit has almost the same chemical and physical characteristics as the Baker or Howland guano. Resting like that on a coral foundation, it has been exposed only to like influences, while the Jarvis crusted deposit, above described, owes its peculiar character to its contact with the gypsum on which it lies and to the action of the sea water.

This gypsum or sulphate of lime is usually soft and amorphous, sometimes crystalline, and, at a depth of eighteen inches or two feet, occurs in hard, compact, crystalline beds. It is of a light snuff color, and where it underlies guano, is mixed with considerable phosphate of lime, which has been washed down from the surface. Similar deposits of sulphate of lime occur on many other elevated lagoon-islands of the Pacific, some of which I shall allude to below. I have also seen gypsum, of similar character and appearance, which occurs in "pockets" or small depressions in the now elevated portions of the coral reef at Oahu, Sandwich Islands, and doubtless due to the same source, the evaporation of sea water.

Unfortunately for the commercial interests of the Jarvis guano, the earlier cargoes (the first one or two) that were brought thence were selected without the aid of chemical analysis, and those in charge mistaking the gypsum for guano, sent home cargoes, the

greater part of which was far from being worth the expense of transportation. The repetition of this error was promptly guarded against by sending a chemist to the island, but it required a longer time for the reputation of the article in the market to recover from the ill effects of such a mistake.

Climate.—The climate of these three islands is similar and very equable. The trade winds are almost constant, and blow in the summer from east by south to southeast, and, in the winter, from east by north to northeast. From October to February, inclusive, on Baker's, I did not observe a point of southing in the wind, while during the summer months there are long periods during which the wind is invariably from south of east. Calms are rare, especially those of long duration. Westerly winds have seldom been observed, except, occasionally, as light puffs on quiet, calm days. On one or two occasions only, in the winter, at Baker's, have any westerly winds of much force been recorded.

The sky is clear and cloudless. The temperature is exceedingly even, ranging from 76° at sunrise to 88° Fahrenheit at the hottest part of the day in the shade. In the sun at noon it stands between 95° and 100°.

Rain falls in light showers not infrequently. Heavy showers are rare and rainy days are unknown in my experience there. During four winter months at Baker's Island, from October 1, 1859, to February 15, 1860, rain fell twenty-three times, generally occurring in light showers or squalls, at intervals of a week or thereabouts, and a general coincidence between the times of occurrence of these showers and the changes of the moon from phase to phase has been observed, but this regularity is not so great, neither at this or other seasons, but that weeks have passed without a drop of rain.

During these four months the least of these showers, measured by conical rain gauge, amounted to $\frac{5}{1000}$ of an inch on a level, and the greatest on December 19, 1859, was $\frac{258}{1000}$ of one inch. From December 14, 1859, to December 20, 1859, inclusive, there fell $\frac{65}{100}$ of one inch. The total amount of the four months' rain was 1·840 inches, of which $\frac{85}{100}$ fell in December.

Although the amount of rain falling in the summer months is much less than that which falls in winter, there are, nevertheless, days in summer on which showers have fallen as heavy as any in the year.

Rain falls most frequently in the night and just before daybreak; sometimes by day, especially if the sky has long been overcast, a rain cloud passes over the island, but I have often observed the remarkable phenomenon of a rain squall approaching the island, and just before reaching it, separating into two parts, one of which passed by on the north, the other on the south side, the cloud having been cleft by the column of heated air rising from the white coral sands.

The position of these islands near the equator and their remoteness from any high land make them favorable places for studying the meteorology of this region. The equatorial current is a matter of great interest. It has a general direction of west southwest, and runs with a great velocity, sometimes exceeding two knots per hour, and, at times, suddenly changing and running quite as rapidly to the eastward.

During the winter months there are days when the swell is very heavy, and the surf breaks violently on the reefs, but in summer there is little or no surf, and especially on the lee side of the island, the water is very smooth. These periods in the winter occur usually at intervals of a few days and prevail during two or three and sometimes more days. In this connection I may allude to the shifting sands at Baker's, which, as I observed there, change their place twice in the year. The western shore of the island trends nearly northeast and southwest; the southern shore east by north. At their junction there is a spit of sand extending out towards the southwest. During the summer the ocean swell, like the wind, comes from the southeast, to the force of which the south side of the island is exposed, while the western side is protected. In consequence the sands of the beach that have been accumulating during the summer on the south side are all washed around the southwest point, and are heaped up on the western side, forming a plateau along the beach two or three hundred feet wide, nearly covering the shore platform, and eight or ten feet deep. With October and November comes the winter swell from northeast, which sweeps along the western shore and from the force of which the south side is in its turn protected. Then the sand begins to travel from the western to the southern side, and after a month or two nothing remains of the great sand plateau but a narrow strip, while on the south side the beach has been extended 200 or 300 feet. This lasts until February or March when the operation is repeated.

Birds, etc.—From fifteen to twenty varieties of birds may be distinguished among those frequenting the island of which the principal are Gannets and Boobies, Frigate Birds, Tropic Birds, Tern, Noddies, Petrels, and some game birds as the Curlew, Snipe and Plover. Of terns there are several varieties. The most numerously represented is what I believe to be the Sterna Hirundo. These frequent the island twice in the year for the purpose of breeding. They rest on the ground, making no nests but selecting tufts of grass, where such may be found, under which to lay their eggs. I have seen acres of ground thus thickly covered by these birds, whose numbers might be told by millions. Between the breeding seasons they diminish considerably in numbers, though they never entirely desert the island. They are expert fishers and venture far out to sea in quest of prey. The Noddies (Sterna stolida) are also very numerous.

They are black birds, somewhat larger than pigeons, with much longer wings. They are very simple and stupid. They burrow holes in the guano in which they live and raise their young, generally inhabiting that part of the deposit which is shallowest and driest. Their numbers seem to be about the same throughout the year. The Gannet and Booby, two closely allied species, (of the genus Sula), are represented by two or three varieties. They are large birds and great devourers of fish which they take very expertly, not only catching those that leap out of water but diving beneath the surface for them. They are very awkward and unwieldy on land, and may be easily overtaken and captured if indeed they attempt to escape at all on the approach of man. They rest on the trees wherever there is opportunity, but on these islands they collect in great groups on the ground where they lay their eggs and raise their young. One variety, not very numerous, has the habit of building up a pile of twigs and sticks, twenty or thirty inches in height, particularly on Howland's where more material of that sort is at hand, on which they make their nest. When frightened these birds disgorge the contents of their stomachs, the capacity of which is sometimes very astonishing. They are gross feeders, and I have often seen one disgorge three or four large flying fish fifteen or eighteen inches in length.

The Frigate Bird (Tachypetes Aquilus) I have already alluded to. It is a large rapacious bird, the tyrant of the feathered community. It lives almost entirely by piracy, forcing other birds to contribute to its support. These frigate birds hover over the island constantly, lying in wait for fishing birds returning from sea to whom they give chase, and the pursued bird only escapes by disgorging its prey, which the pursuer very adroitly catches in the air. They also prey upon flying fish and others that leap from sea to sea, but never dive for fish and rarely even approach the water.

The above are the kinds of birds most numerously represented and to which we owe the existing deposits. When the islands were first occupied they were very numerous but have since been perceptibly decreasing.

Besides these are the Tropic Birds which are found in considerable numbers on Howland's Island, but seldom on Jarvis' or Baker's. They prefer the former because there are large blocks or fragments of beach rock, scattered over the island's surface, under which they burrow out nests for themselves. A service is sometimes required of this bird which may, perhaps, be worthy of notice. A setting bird was taken from her nest and carried to sea by a vessel just leaving the island. On the second day, at sea, a rag, on which was written a message, was attached to the bird's feet, who returned to the nest, bringing with it the intelligence from the departed vessel. This experi-

ment succeeded so well that, subsequently, these birds were carried from Howland's to Baker's Island, (forty miles distant), and, on being liberated there, one after the other, as occasion demanded, brought back messages, proving themselves useful in the absence of other means of communication.

There are several varieties of tern, those described above, however, being the only kinds that are found in very considerable numbers. The game birds, snipe, plover and curlew, frequent the islands in the fall and winter, but I never found any evidence of their breeding there. They do not leave the island in quest of prey but may be seen at low tide picking up their food on the reef which is then almost dry.

Some of the social habits of these birds are worthy of remark. The gannets and boobies usually crowd together in a very exclusive manner; the frigate birds likewise keep themselves distinct from other kinds; the tern appropriate to themselves a certain portion of the island; each family collects in its accustomed roosting place but all in peace and harmony. The feud between the fishing birds and their oppressors, the frigate birds, is only active in the air; if the gannet or booby can but reach the land and plant its feet on the ground the pursuer gives up the chase immediately.

Beside the birds there were but few original inhabitants found upon the islands. Among those I observe several varieties of spiders, at least two of ants, a peculiar species of fly that attaches itself to the larger birds, and the common house fly, which latter, however, may have been recently introduced. They as well as common red ants are exceedingly abundant.

Rats were found on all these islands, especially on Howland's, where they had become astonishingly numerous. It would seem that they had been carried there long ago, as there are no traces of recent shipwreck on the island, and had multiplied extensively. On Jarvis' Island they were much less numerous, and were probably brought by a ship that was wrecked there thirty years since. They subsist on eggs, and also, as I observed on Baker's Island, by sucking the blood of the smaller birds—the tern and noddies; and in this connection I may observe that these smaller kinds of birds, described above, are almost entirely wanting on Howland's, and their absence, I think, may be attributed to the depredations of the rats. These rats of Howland's Island were almost as numerous as the birds. They are of very small size, being hardly larger than a large mouse, and, I think, must have degenerated from their original state in consequence of the change of climate, food and condition of life. They had completely overrun the island, and on its first occupation by men were a great annoyance. For many nights in succession a barrel containing a few oats caught over 100, and I have known over

3,300 to have been killed in one day by a few men employed for the purpose.

A species of small lizard was also found in great numbers on Howland's Island, some specimens of which I had preserved in spirit, but the package containing them was lost on the voyage home.

Remains of former visitors.—There are some interesting traces on this (Howland's) island of former visitors or residents. Excavations and mounds in the centre of the island, among the thickets of brushwood, referred to above, are evidently the work of man. The most extensive of these excavations is several hundred feet long, and about one hundred feet wide, and ten or fifteen feet deep, forming a gully or ditch, on each side of which the sand and gravel is carefully banked up and kept in its place by walls laid up of coral stone, (blocks of beach and reef rock).

The trees themselves may possibly owe their existence here to the originators of these works, for the sides of this gully are covered by a growth of wood which, unless younger than the rest, would show the trees to be of more recent origin than the excavation.

It is said to be of a species called by the natives of the Sandwich Islands "Kou,"* which abounds on many islands of the Pacific. In the same vicinity there are also the remains of what were low, flat mounds of regular shape, formed of gravel and walled up all around, being about a foot high, and just such as I have observed are used by many South Sea Islanders for the foundation and floor of their houses. In another part of the island, near the western beach, some remains of a hut were found, and near by the fragments of a canoe, some pieces of bamboo and a blue bead. Here also was found, buried under a foot of sand, a human skeleton, the greater part of which, on being exposed to the air, crumbled to dust, leaving only two or three bones in condition to be preserved.

On the south end of the island there is a foot-path laid to cross a bed of coral debris or beach accumulations. The edges of the corals being rough, sharp and painful to the feet, the paths seems to have been laid for the convenience of passengers across this end of the island. It is several hundred feet long, made of flat, smooth stones, at convenient distances apart, for stepping from one to the other. They were evidently laid by hand, as they lie in a direction which forms nearly a right angle with the ridges made by the sea. It is probable that the originators of these works were South Sea Islanders. It sometimes happens that they are drifted off to sea by currents in their canoes, and such a party may have been thrown upon this island. No implements or other traces of civilized people have been found.

* Not to be confounded with "Koa," a species of acacia, and quite a different tree. I have seen the Kou alluded to somewhere as a species of *cordia*.

It is not unlikely that the lizards which abound on the inhabited islands of the Pacific were brought here by these people, and the rats, possibly, came from the same source.

Other Islands.—As already observed, the discovery of these deposits of guano, the extent and value of which were at first greatly exaggerated, induced fortune-seeking parties to explore the Pacific in the hope of finding many more of similar character. Under the act of Congress of 1856, granting American protection to the discoverers and occupants, under certain conditions, of such newly found deposits, nearly all the islands found on the charts within ten degrees north or south of the equator and within 150° and 180° W. were represented as possessing deposits of guano, and claimed by parties who evidently knew but little of their true condition.

A list, forty-eight in number, comprising nearly all of these islands, was published in the New York Tribune, in March, 1859, and was copied and discussed by Mr. E. Behm, in his interesting and valuable article, entitled "Das Amerikanische Polynesien," printed in Petermann's *Mittheilungen*, for 1859.

Of these islands, a number of which I have myself examined, it is safe to assert that some, although having a place on the charts, do not really exist, while many are of very doubtful existence; in some cases two or more names are applied to the same island; some are inhabited, others are covered with trees and vegetation, and very few have guano on them.*

* The following is the list referred to. Those named in the first column are islands whose existence and position is well authenticated, and the greater part of which I have myself visited. Those in italics are either known or said to be guano islands. Those marked with an asterisk are inhabited. Some of the islands mentioned in the second column are known certainly to exist, and are described by various navigators, while others are doubtful, but I am unable to add any *positive* information concerning any of them. The existence of those in the third column is considered as highly improbable, at least in the position commonly assigned to them.

I.	II.		III.
Baker's,	Caroline,	Danger, (6° 30′ N.,	Arthur's
Jarvis',	Ann's,	162° 32′ W.),	Favorite,
Howland's,	Staver's,	Makin,	Farmer's,
Malden's,	Flint, (10° 32′ S.,	Matthew's,	Sideron's,
Birnie's,	151° 05′ W.)	Barber's.	Flint, (11° 26′ S.,
Phœnix's,	Baumann's,		162° 48′ W.)
Enderbury's,	Rogewein's,		Walker's,
Christmas,	Gronique,		Sarah Anne,
Clarence,*	Frieuhaven,		Samarang,
Duke of York,*	Quiro's,		David's.
Penrhyn's,*	Low,		
Rierson's,*	Pescado,		
Humphrey's,*	Ganges,		
Danger,* (10° 0′ S.,	Frances,		
165° 56′ W.),	Mary Letitia's,		
Palmyra,	Kemin's,		
Sydney,	America,		
Mary's,	Prospect,		
Nassau.			

The following named islands, in particular, have been supposed, erroneously, as regards some of them, to have guano deposits:

		Latitude.	Longitude.
Phœnix Group.	McKean's,	3° 35′ S.,	174° 17′ W.
	Phœnix,	3° 40′ S.,	170° 52′ W.
	Enderbury's,	3° 08′ S.,	174° 14′ W.
	Birnie's,	3° 33′ S.,	171° 33′ W.
	Malden's,	4° 15′ S.,	155° W.
	Johnston's,	16° 53′ N.,	169° 31′ W.
	Christmas,	1° 53′ N.,	157° 32′ W.
	Starve, Starbuck or Hero,	5° 40′ S.,	155° 55′ W.

Of the above those of the Phœnix group are probably the most important. McKean's Island has been occupied since 1858, and several cargoes of guano of good quality have been brought from it to this country. It is a low island, circular in form, not exceeding three-fourths of a mile in diameter. Like Jarvis, it once contained a lagoon though not elevated so high above the sea. Its surface is consequently depressed, and is so much lower than the beach that at high tides the guano deposit is sometimes covered by two feet of water. As at Jarvis, a deposit of sulphate of lime has resulted from the evaporation of sea water in the basin, forming the foundation on which the guano rests; and owing, probably, to frequent inundations, the two have become so intimately mixed that the quality of much of the guano is considerably impaired. The better specimens contain about fifty per cent phosphate of lime mixed with much sulphate of lime. Much of the deposit is covered by a foot of coral mud, which has been spread out over the part adjacent to the beach.

Phœnix's Island is likewise very small, nearly circular, and less than a half mile in diameter. The centre is considerably lower than the beach, which is about eight or ten feet high, and it is often flooded at high tides. I was unable to land on this island, and my opportunities for observation were confined to shipboard. The guano deposit cannot be very extensive though said to be of good quality.

Enderbury's Island is described as an elevated lagoon, about eighteen feet high, three miles long by two and a half broad. It is said to contain deposits of guano, as is also its neighbor, Birnie's Island, of which I am unable to give any positive information, having never visited either.

Malden's is a large island, ten miles long, and said to be about forty feet high. I believe it is an elevated lagoon, but much of the guano deposit lies on the elevated ridge. Specimens which I have examined, though free from sulphate, were much adulterated by coral sand. Excepting McKean's, no cargoes have been brought from these islands just alluded to. From Johnston's Islands one or two cargoes have been brought to this country, the greater part of which proved, I believe, to be sand. These

are described as three small islands (probably islets of one atoll) containing but little guano and that much mixed with coral sand.

Christmas Island is a well-known lagoon thirty miles long, trending east and west, having much vegetation. Much has been said by speculators of its rich deposits, but I have good reason to believe that there is no guano, worthy of mention, on the island. Samples that I have examined were chiefly coral sand.

Starbuck's, Starve or Hero Island is an elevated lagoon, and is worthy of mention because, like Jarvis', McKean's and other islands of similar structure, it contains a large deposit of gypsum. Its supposed guano I have found to consist of the hydrated sulphate of lime, containing about twelve per cent of phosphate of lime and colored by a little organic matter.

So far as my observation extends, all elevated lagoons have similar deposits of gypsum.

As regards the distribution of these phosphatic guano deposits I believe them, in this region of the Pacific, to be confined to latitudes very near the equator where rain is comparatively of rare occurrence. In latitudes more remote from the equator than 4° or 5° heavy rains are frequent, and this circumstance is not only directly unfavorable to the formation of guano deposits but it encourages vegetation, and when an island is covered with trees and bushes, the birds preferring to roost in them, there is no opportunity for the accumulation of guano deposits.

New York, August, 1862.